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Published in:
Transport Research Arena TRA2016

Link to article, DOI:
10.1016/j.trpro.2016.05.403

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Kapetanis, G. N., Psaraftis, H. N., & Spyrou, D. (2016). A Simple Synchro – Modal Decision Support Tool for the Piraeus Container Terminal. In *Transport Research Arena TRA2016* (Vol. 14, pp. 2860-2869). Elsevier. Transportation Research Procedia https://doi.org/10.1016/j.trpro.2016.05.403

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 2860 – 2869

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

A simple synchro – modal decision support tool for the Piraeus container terminal

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Abstract

The concept of Synchro modality is effectively an evolution of a multimodal supply chain. It integrates different transport modes and gives shippers and logistics service providers the freedom to deploy different modes of transportation in the same chain and in a flexible way so as to gain the desired outcome according to their priorities in a certain trip. Time, costs and emissions are certainly the three most relevant parameters when talking about a multimodal transportation chain. In most cases the logistics provider has set priorities to conform with, and obviously above mentioned constrains influence each other in an adverse way. With the development of ICT technologies and systems installed on board and on shore and with a simple decision support system fed with input from tracking and tracing systems or traffic monitoring systems, one can easily and flexibly plan his transportation job and maintain his set priority while in parallel keeping the remaining two parameters in control. Down times for example could be eliminated and efficiency gains could be achieved with decreased environmental footprint.

The Port of Piraeus is the largest Greek seaport and one of the largest ports in the Mediterranean Sea basin. It exhibits an impressive container traffic growth rate over the last 4 years triggered by its partial privatization and a recently completed hinterland connection to the rail network, which associated the port with the South-Eastern European corridor e.g. the route Far Eastern ports–Piraeus–Prague.

The current paper will present an easy to use simple tool to continuously assess even during the transportation event all the alternative modes for a given destination in terms of time cost and emissions. An analytical fully parameterized model will be the basis for this tool which will be run for the chain Shanghai–Piraeus–Prague. The overall scenario is as follows: A container ship is arriving from China to the Piraeus Container Terminal. One of its containers is destined to an inland Enterprise in Prague. The

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.403

most common way for transportation to Prague is rail, but also truck could be an alternative solution and of course a combination of a Short Sea Shipping part to Thessaloniki and then truck or train to Prague. Emphasis in the calculations will be given to emissions for all the modes and relations will be shown with time and cost.
The tool developed is based on the case study above, being however open architecture software it can be expanded and applied to other ports and routes. The final outcome will be an easy and user friendly tool with the possibility to alter different input parameters and receive quickly a useful decision support system for the shipper or the logistics providers. Finally, there are two loops foreseen for the runs of the program. The required input parameters at each stage are either directly fed to the program if available (e.g vessels ETA and position through GPS, VTS, ETC) or calculated if this is not the case.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: maritime transport; multimodality; synchro-modal transportation; marine emissions; transport emissions; transport cost; transport time; transport IT technologies

1. Scope of work

Based and in continuation of work done namely “The Concept of Synchro-Modality and how it May Help Reduce Emissions: A Case Study for the Piraeus Container Terminal”, this work concentrates only in the transportation of one TEU from Shanghai through Piraeus to Prague. The leg Shanghai–Piraeus is the same for all envisaged alternatives which comprise road, rail and a combination of sea, road/rail for the part Piraeus–Prague. All above options are calculated in a simple but expandable and flexible tool in terms of emissions, cost and time and the results are collectively presented for each root and for each criterion, highlighting the root with the desired priority.

Nomenclature

GHG’s	Green House Gases		
SOx	Sulphur Oxides		
NOx	Nitrogen Oxides		
PM	Particulate Matter		
ICT	Information and Communication Technologies		
LSP	Logistics Service Provider		
dtw	Dead weight in tonnes		
TEU	Twenty Foot Equivalent Unit		
ETA	Estimated Time of Arrival		
OSE	Hellenic Railway Organisation		
S-S-R	Ship – Ship – Rail		
S -R	Ship – Rail		
S - T	Ship - Truck		
OECD	Organisation for Economic Co-operation and Development		
gr	grams	t	tonnes
d	days	km	kilometres
nm	nautical miles	h	hours

2. Synchromodal Transportation – the concept

The concept of synchromodality is effectively an evolution of a multimodal supply chain applying ICT in order to gain efficiency, i.e. minimize costs and time. In the case of transportation of containerized freight, traffic is basically partitioned in three segments: pre haul (or first mile for the pickup process), long haul (door to door transit of containers), and end – haul (or last mile for the delivery process). According to Steadie Seifi et al (2014) in most cases, the pre haul and end – haul phases are carried out via road, but for the long – haul transportation road, rail air and water modes can be considered. The middle part of the chain, namely the long – haul leg usually involves combining different modes, such as ships trucks and rail in most cases when speaking about containerized cargo

Synchromodal transport emerged recently as a new logistics concept in freight transport. It integrates different transport modes and gives logistics service providers (LSPs) the freedom to deploy different modes of transportation in a flexible way, which on the one hand enables better utilization of the existing infrastructure capacities, and on the other hand allows to the provider or the shipper to set their priorities for the specific consignment and have different options even during the actual transportation period. Taking advantage of the advanced ICT systems used in the marine industry, this means that even during the transportation event and according to the priorities set by the shipper/logistics provider and the prevailing conditions (weather, traffic congestions etc.) one can alter the transportation mode to better suit to the desired result.

3. The calculation tool

An open architecture expandable tool was used to be used in a spiral form and updated as soon as new actual data are available during the whole chain. In this way it can be run for preliminary calculations and decisions at the planning stage but also updated continuously during the trip phases to assess the progress and cater for unexpected or unforeseen parameters which could make the change of a transportation phase essential in order to stick to the given priorities of the specific transportation job. The calculation methods applied are explicitly described in [7], and for economy reasons are not explained once more in this paper. However, it should be highlighted that the data insertion modes are actually 2, namely one at the preliminary/decision phase time cost and emissions are calculated while during the whole chain where iterations are run, and if available actual data could be inserted in the tool. In this way the picture becomes more realistic and hence delays or other unforeseen parameters are implemented helping to find the right decision e.g shifting to another transport mode. This exactly is also the essence of synchromodal transportation and that is also the reason why times such as unloading, customs papers etc are not separately captured.

4. Sea-rail combination

A 47,000 dtw, 2809 TEU container ship coming from China is arriving to the Piraeus Port container Terminal. One of its containers destined to an inland Enterprise in Prague. The Piraeus Container Terminal operator unloads the mother vessel, and dependent on the railway schedules to Prague either reloads it immediately or after a certain waiting time on a train for its last destination Prague.

For the main Sea Leg Shanghai–Piraeus, which is obviously common for all three envisaged transport combinations the tool calculations are:

- Sea Leg Emissions Shanghai–Piraeus

The tool has the capability to calculate the sea leg emissions in two different ways. Either precisely, if the ship and its performance parameters are known, or if not on an emission factors basis. In this case the first option is shown, while the second one will be applied later on in the feeder leg between Piraeus and Thessaloniki.

The ships input data required are shown in the following table which is part of the tool:

Distance Piraeus–Shanghai: 7895 nm

Table 1. Data of the chosen ship.

Vessel Data			
SHIP TYPE	Container Vessel	MAIN ENGINE POWER-MCR	17210/88 rpm
SIZE CATEGORY		AUXILIARY ENGINE POWER	3* 2000 kW
DWT	47272 t	SERVICE SPEED AT 100% MCR	22 kn
DISPLACEMENT	59407 t	TYPE OF FUEL, ME	RMG 380
MAX PAYLOAD	2809 TEU	CARBON COEF, ME	3114400 (g CO_2/t Fuel) FOR HEAVY FUEL
MAIN ENGINE TYPE &MODEL	K.H.I.C. MAN-B&W 7S70MC	S CONTENT, ME	MAX 4,5%
		NOX COEF, ME	17g/KWh @100% LOAD,

Table 2. Speed – consumption curve and fuel characteristics.

SPEED VS BUNKER CONSUMPTION CURVE								
SPEED		ME power	SFC ME	ME FC	AE FC	AE FC	Total FC	Total FC
knots	RPM	kW	t/kWh	t/day	t/day	t/day	t/day	t/day
					WITHOUT REFER	WITH REFER	WITHOUT REFER	WITH REFER
16	73	9819	182	43				
17	78	11977	184	53	4	8	57.0	61.0
18	80	12923	184	57	4	8	61.0	65.0
19	83	14432	179	62	4	8	66.0	70.0
20	85	15500	170	63.2	4	8	67.2	71.2
21	87	16620	170	67.8	4	8	71.8	75.8
22	88	17200	170	70.2	4	8	74.2	78.2
TYPE OF FUEL, AE				RMG 380/MDO				
CARBON COEF, AE				3206000 (g CO_2/t Fuel) FOR DIESEL OIL				
S CONTENT, AE				max 4.5% RMG/max 0.1 for DMA				
NOX COEF, AE								
FUEL CONSUMPTION IN PORT				7 t/day				
SERVICE SPEED, LADEN				18-20 kn				
SERVICE SPEED, BALLAST								

With above data the results in terms of emissions, time and costs for the sea leg Piraeus–Shanghai and a speed of 16 kn is shown in the tables below.

Table 3. Container vessel emissions for the Shanghai–Piraeus trip.

[kg/t]		[gr/t*nm]		[gr/t*km]	
CO_2	NO_X	CO_2	NOx	CO_2	NOx
83,2755	1.8914	10.5479	0.2396	6.5541	0.1489
SO_2	PM	SO_2	PM	SO_2	PM
[kg/t]		[gr/t*nm]		[gr/t*km]	

Table 4. Container vessel emissions in [t] for 1 TEU calculated for a specific ship and for the trip Piraeus–Prague.

[t/TEU] Pir–Prague	
CO_2 emissions	NO_X emissions
1.665509422	0.037828605
SO_2 emissions	PM emissions
0.026269865	0.007040324

- Sea leg Shanghai–Piraeus time calculation

The time needed is calculated from the distance and the ships speed and the results calculated by the tool developed are given in the following table/excerpt of the tool:

Table 5. Time calculations Shanghai–Piraeus.

Route	Distance *[nm]	Vessel speed [kn]	Trip duration at sea [h]	Trip duration at sea [d]	days at each port [d]	operational days/year
Shanghai–Piraeus	7895.0	16.0	493.4	20.6	1	340

- Cost calculations for the Sea leg Shanghai–Piraeus

The cost can be inserted either directly to the program if known, or otherwise calculated on the basis of the charter rate of the specific vessel and for the specific route. The spot rate is requested as input in USD/tonne (or in USD/day or the TEC (Time Charter Equivalent) in USD/day for other modelling purposes. A dummy variable (0/1) is used to define which input is given).

For this application spot rates are in use and the results are shown in the following tables

Table 6. Cost profile Shanghai–Piraeus.

	[USD/t]	TCE [USD/d]	Rate used	$/TEU
Spot rate	17.00	20.000	-	340
Charter type	1	Voyage Charter	1	

- Rail calculations Piraeus–Prague

Rail emissions are calculated on the basis of emission factors as shown in the table below The OECD figures are used for this work as shown in the tables below

Table 7. Rail air emission factors [gr/t*km].

Pollutant	OECD
CO	0.15
CO_2	48
HC	0.07
NO_x	0.4
SO_2	0.18
Particulates	0.07
VOC	

Table 8. Rail emissions Piraeus–Prague.

Pollutants	TEU Weight [t]	Distance [km]	Emissions for 1 TEU [t]
CO_2	20	1536	1.474560
NO_x	20	1536	0.012288
SO_2	20	1536	0.0055296
Particulates	20	1536	0.0021504

For the time and cost calculation the procedure is following:

Route distance Piraeus–Prague 1536 km.

Calculating the time needed with the use of a dummy variable there is the option to either insert the given time from the Railways time schedule (here OSE) or to calculate it with an freight train average speed as found in the literature.

The HP/Cosco agreement coincided with completion of a new 17 km (10.6-mile) railway line connecting Piraeus with the main European freight network. Greek state rail operator Trainose can now forward a train to HP's key European hub in Prague in five days,

Time needed (OSE) 5d.

A more generic however method to calculate rail time needed between two cities is to use average freight train speeds from the literature. Adopting an average speed total freight trains 28 km/h *(ROMANIA Provisional results, 2004)* the time needed for any rail leg is calculated

Table 9. Time for rail leg Piraeus–Prague.

Distance [km]	Average speed [km/h]	Time calculated [d]	[h]	Real time offer [d]
1536	28	2.29	54.8571429	5

For the cost calculation again either the real cost from the offer can be used if available or the cost can be calculated using cost rail factors:

Given a cost rail in Europe of 0.06 €/(t*km) the total cost for the transportation of 1 TEU of 20 t weight from Piraeus to Prague amounts to 184.32 €.

Table 10. Rail cost Piraeus–Prague.

	Cost Factor [€/t*km]	Distance [km]	Weight/TEU [t]	Cost [€/TEU]	€/$	Cost [$/TEU]
Pir.–Prague	0.006	1536	20	184.32	1.125	163.84

5. The Short Sea Shipping (SSS) alternative

This scenario involves a Short Sea Shipping (SSS) leg from Piraeus to Thessaloniki and then rail (or truck) to Prague.

The SSS leg calculations are according to the afore said as follows

Emissions Piraeus Thessaloniki for a feeder vessel are here calculated with both ships data and emission factors and are then compared to each other and validated through real results for the specific ship as received from OLP and MSC.

- Calculation through ships data and fuel consumption

Applying the tool as for above ship and route Shanghai–Piraeus the calculation steps and the results are the following:

Table 11. Ships data for the feeder Piraeus–Thessaloniki.

Distance (Pir.–Thes.) [nm]	DWT [t]	ME power [HP]	Speed [kn]	Service speed [kn]	Actual fuel cons [t/d]	AE fuel cons at sea and in port [t/d]
252	18423	13544	18	15	17.66	0.5/1

Table 12. Feeder vessel emissions in [t] for 1 TEU calculated for a specific ship and for the trip Piraeus–Thessaloniki.

[t/TEU] Pir.–Thes.	
CO_2 emissions	NO_x emissions
0.080082873	0.001818917
SO_2 emissions	PM emissions
0.001263137	0.000338521

- Emissions calculation through emission factors

Using a dummy variable the tool offers the possibility of calculating the emissions also on an emission factor basis for the case that the specific ship data are missing. It is shown here below with the aim primary to compare and validate the results:

Table 13. Feeder vessel emissions calculated on the basis of OECD emission factors Piraeus–Thessaloniki.

Emission factors [gr/t*km]	Befahly	OECD	Whitelegg	Emissions /TEU for Pir- Thes [gr]
NO_x	0.58	0.5	0.4	5.35671E-05
CO_2		40	30	0.004285371
PM	0.04	0.03		3.21403E-06
SO_2		0.05		5.35671E-06

Comparing the above results derived from the two different methods, the values are indeed within the same range with the ones based on the specific ship data and fuel consumption being obviously more accurate. However for using the tool in a pre-decision phase it is helpful to have the emissions factors values which obviously give precisely the overall picture.

Time and cost for this leg are calculated as above presented for the Shanghai–Piraeus leg

Table 14. Time calculation for the feeder vessel Piraeus–Thessaloniki.

	Distance	Vessel speed	Trip duration		Days at each port
FROM	[nm]	[kn]	[h]	[d]	[d]
Piraeus	252.0	15.0	16.8	0.7	1
TO	[km]				
Thessaloniki	466.704				

Table 15. Cost calculation 1 TEU Piraeus–Thessaloniki.

Cost Calculation for 1 TEU on a time charter basis	[$/d]
Spot Rate	30.000
TCE	
Transportation cost [$/t*nm]	0.020528965
Cost for 1 TEU 20t [$]	103.4659852

(For the cost calculation the cost approximately is 150$/TEU as stated by the liner service operators for the Piraeus to Thessaloniki trip and for the given vessel. The tool can also calculate it on the basis of the time charter of a ship or the spot rate or even the TCE (Time charter equivalent). In the table below the calculation is shown based on the ships time charter).

6. Thessaloniki–Prague by rail and Piraeus–Prague Thessaloniki–Prague by truck

Finally to conclude the envisaged transportation schedule the remaining route from Thessaloniki to Prague is calculated similarly as done above for the part Piraeus–Prague and having two different alternatives, namely rail or truck.

Table 16. Rail emissions Thessaloniki–Prague.

Pollutants	TEU Weight [t]	Distance [km]	Emissions for 1 TEU [t]
CO_2	20	1238.76	1.189210
NO_x	20	1238.76	0.00991008
SO_2	20	1238.76	0.004459536
Particulates	20	1238.76	0.001734264

- Rail Time and Cost

In the same way the rail time and cost for the Piraeus leg was calculated the respective results are:

Table 17. Rail time Thessaloniki–Prague.

Distance [km]	Average speed [km/h]	Time calculated [d]	[h]	Real time offer [d]
1238.76	28	1.843392857	44.2414286	4

Table 18. Rail cost Thessaloniki–Prague.

	Cost Factor [€/t*km]	Distance [km]	Weight/TEU [t]	Cost [€/TEU]	€/$	Cost [$/TEU]
Thess.–Prague	0.006	1238.76	20	148.6512	1.125	132.1344

- Truck emissions time and cost

The third alternative from Piraeus to Prague lies within road transportation, i.e. loading the container directly in Piraeus to a truck for its final destination namely Prague or from Thessaloniki after the SSS leg. For these two road routes emissions time and costs are calculated whereby if real figures from offers are at hand they can be inserted in the calculation. Results are shown below:

Table 19. Truck emissions Piraeus–Prague and Thessaloniki–Prague.

Pollutants	OECD Em. factors [gr/t*km]	TEU Weight [t]	Distance P–P [km]	Emissions for 1 TEU P-P [t]	Distance T–P [km]	Emissions for 1 TEU T–P [t]
CO_2	140	20	1997	5.591600	1526	4.272800
NO_x	3	20	1997	0.119820	1526	0.091560
SO_2	0.18	20	1997	0.007189	1526	0.005494
Particulates	0.17	20	1997	0.006790	1526	0.005188

Table 20. Truck cost for Piraeus–Prague and Thessaloniki–Prague.

	Cost Factor [€/t*km]	Distance [km]	Weight /TEU [t]	Cost [€/TEU]	€/$	Cost [$/TEU]
Pir.–Prague	0.1046	1997	20	4178	1.125	3714
Thess.–Prague	0.1046	1526	20	3192	1.125	2838

Table 21. Truck time for Piraeus–Prague and Thessaloniki–Prague.

	Distance [km]	Av. Speed [km/h]	Time [h]	Time [d]
Pir.–Prague	1997	50	39.94	1.664166667
Thess.–Prague	1526	50	30.52	1.271666667

7. Synthesis and comparison of the results

In the following graphs the different transportation alternatives are compared in terms of emissions time and costs. Summarizing these four modes for transporting a container from Shanghai to Prague are schematically shown in the figure below.

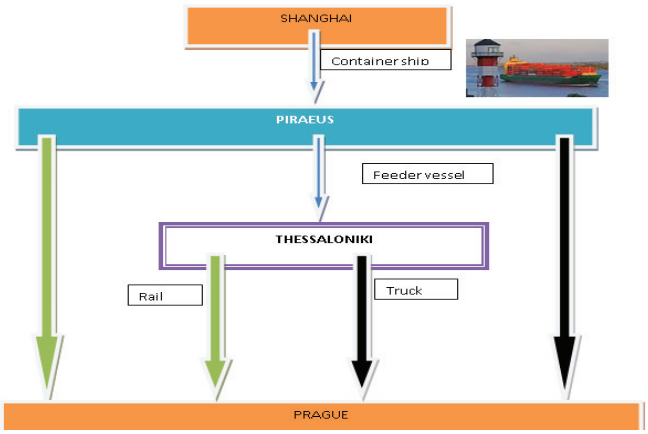

Fig. 1. Shanghai–Prague the four envisaged transportation modes combinations.

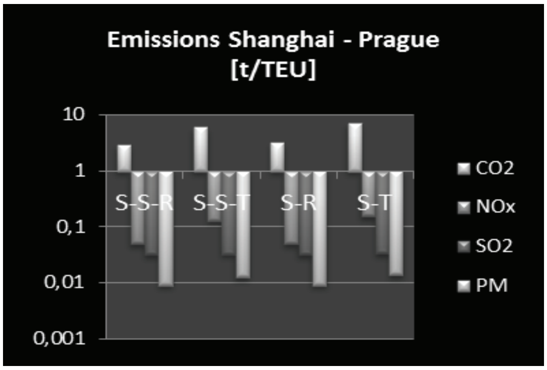

Fig. 2. Emission /TEU for all combinations Shanghai–Prague.

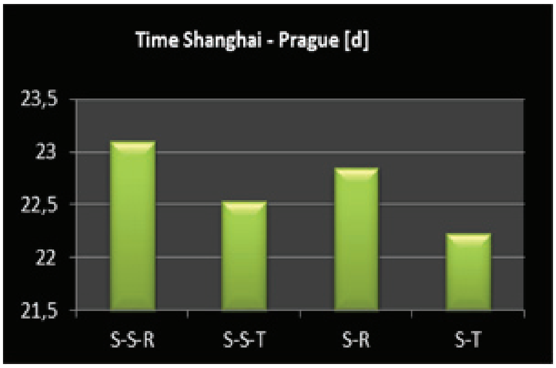

Fig. 3. Total time for all combinations Shanghai–Piraeus.

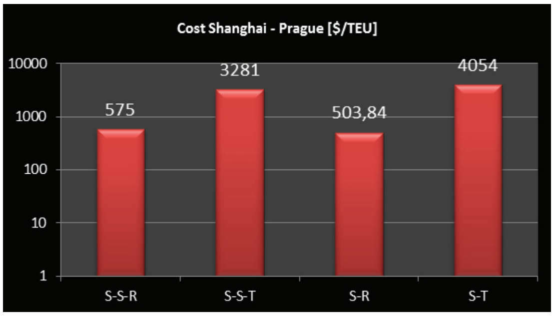

Fig. 4. Calculated cost for all four combinations Shanghai–Prague.

Comparing above results it can be concluded that in terms of emissions the best combination is the S-S-R one followed by the S-R, while in terms of time ship and truck is the faster. Finally, ship – rail combinations are much more cost efficient than combinations involving road transportation. It should be stressed again here that loading/unloading time eventual storing and so on have not be taken into account since this is the first run in the preliminary/decision phase.

8. Conclusions

Based on the work done previously a simple tool was developed allowing at the decision phase to have a preliminary view on the available transportation options and prioritize them according to the actual needs. During the journey the program can be fed with actual data of speed cost and time delivering thus more accurate information. In such a way the initially planned combination can be reset or partially changed, thus keeping the whole view of the effects that a possible change could have.

However and apart from the voyage planning where the tool is primarily intended for, one can analyse the results from another perspective which is of strategic nature. A useful insight is derived from the results attributed to each transportation mode. The relative trends are of course well known from the literature and the experience but the results of the tool firstly relate to specific routes and secondly provide figures that consolidate these trends. Ships are the greener most effective and cheapest transportation mode with a cost ratio to road of approx. 1:6. If the emissions ratio to road and rail is envisaged the results are even more impressive. The CO_2 ratio to rail is 1:7 and to truck approx. 1:20.

On the other hand in terms of time road transportation is faster but also much more costly and rail has compared to road a good eco profile and a better cost figures.

Finally the tool is also flexible and allows either rough or detailed calculation dependent on the data available and can be adapted to different ports and inland hubs/destinations

Future work could include the insertion of ship liner services, truck and rail schedules for the port of Piraeus and also for example just in time arrival information so that the tool will automatically select and propose the speed of the ship as well as the transportation modes for the inland journey to the final destination.

Acknowledgements

This work has been carried out in the context of the research activities of the Centre of Excellence in Ship Total Energy-Emissions-Economy of the National Technical University of Athens, School of Naval Architecture and Marine Engineering. The financial support provided by the Lloyds Register Foundation (LRF) to the Centre is gratefully acknowledged. LRF helps to protect life and property by supporting engineering-related education, public engagement and the application of research.

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